LIGO

# The reality of Mirrors?

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GariLynn Billingsley
Liyuan Zhang
Zygo…
CSIRO…

LIGO

# Overview

- Initial LIGO
  - » Some things we got wrong
- Advanced LIGO
  - » Some things we got right
  - » Some things we're still working on
- Next Generation
  - » Tools we have on hand

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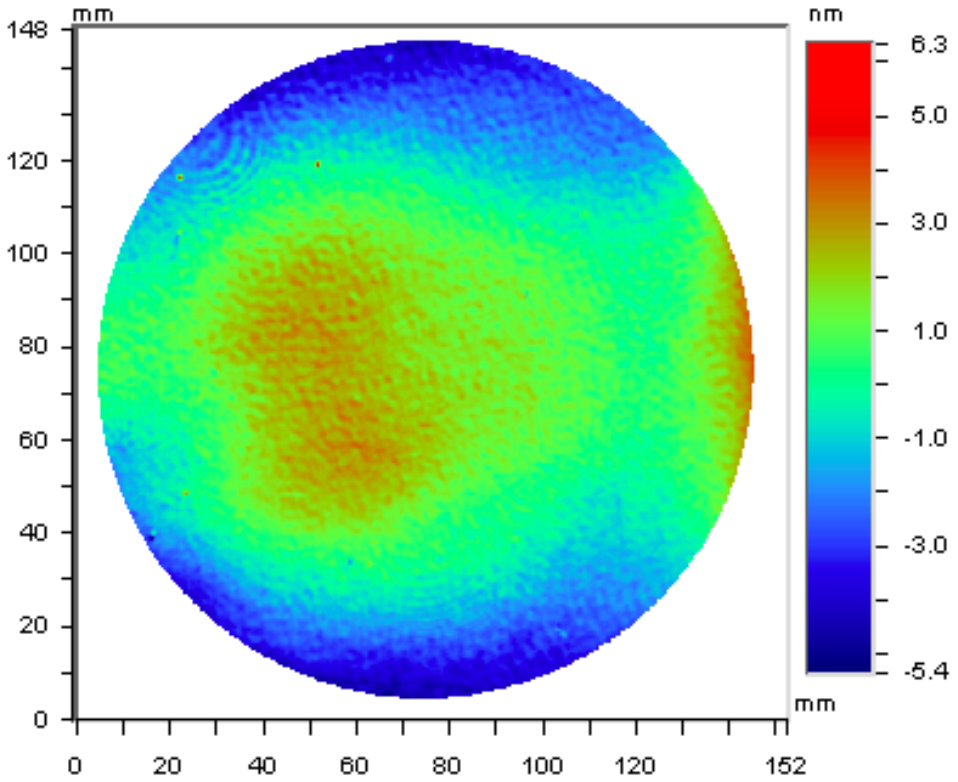
# Error in iLIGO calibration file

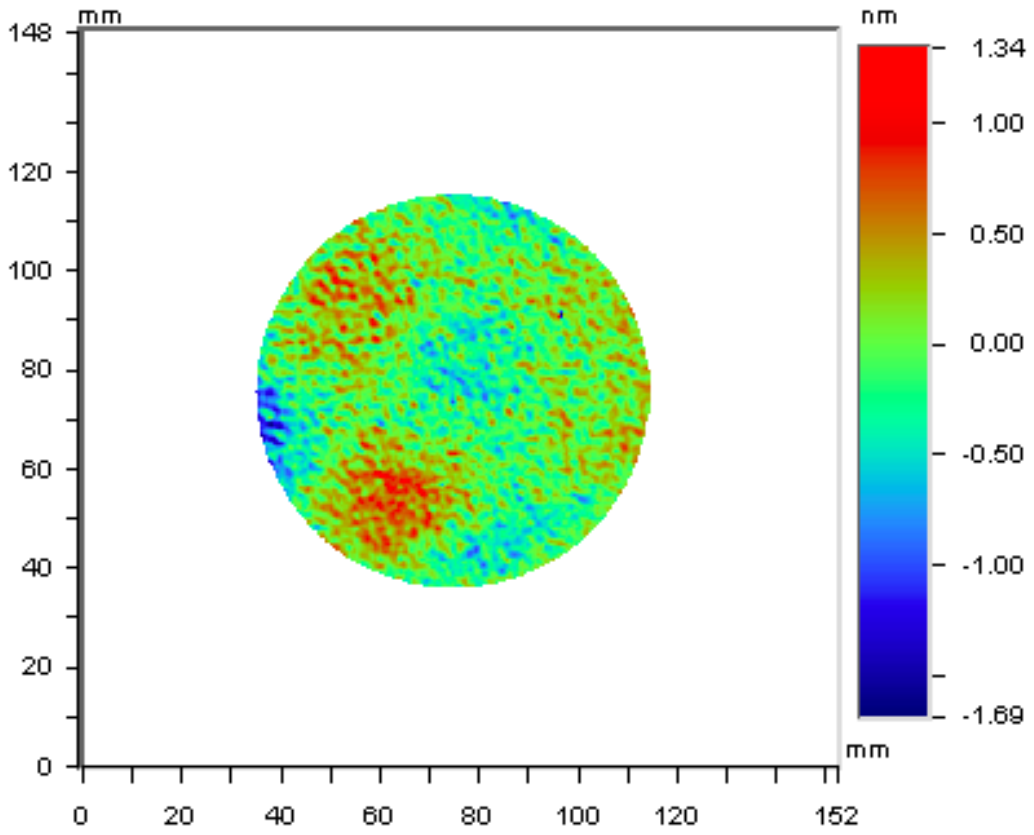



**11.7 nm PV over 150mm, Mostly power,**
**The instrument has been realigned, so the original error may be different**

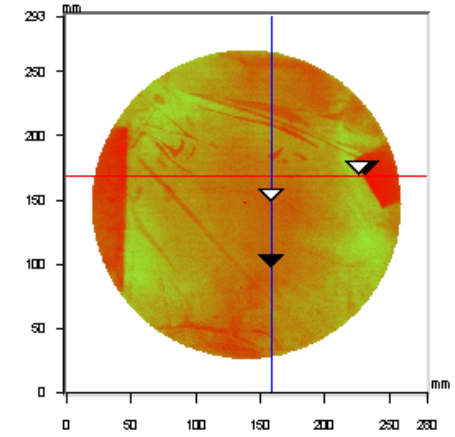
# Power subtracted, analyzed over beam size

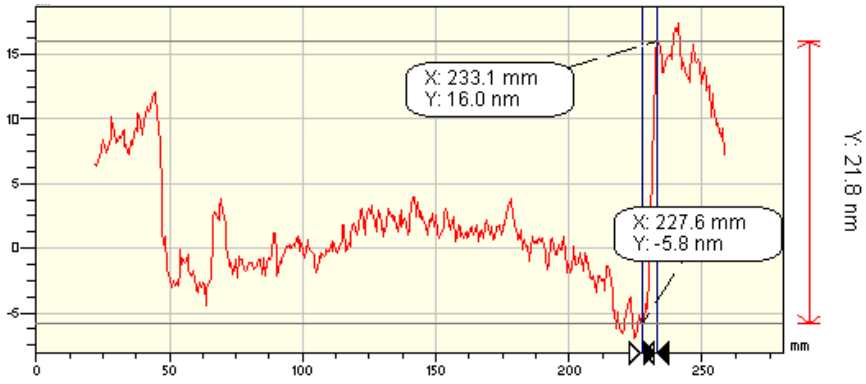
**Rms = 0.35 nm**

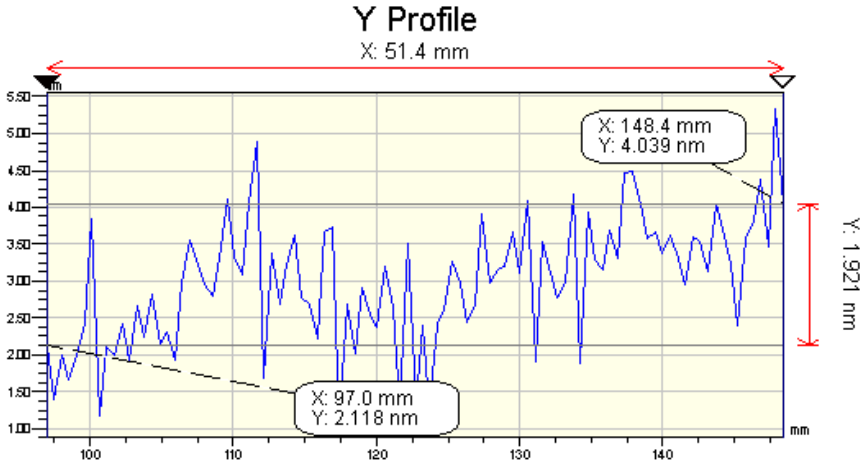
**ILIGO Optic figure is Still better than iLIGO metrology**



# iLIGO too much cleaning before coating extreme example ~20 nm






| | | | | |
|---|---|---|---|---|
| X | 159.16 | - | - | mm |
| Y | 168.57 | - | - | mm |
| Ht | 0.81 | - | - | nm |
| Dist | | | - | mm |
| Angle | | | - | ° |

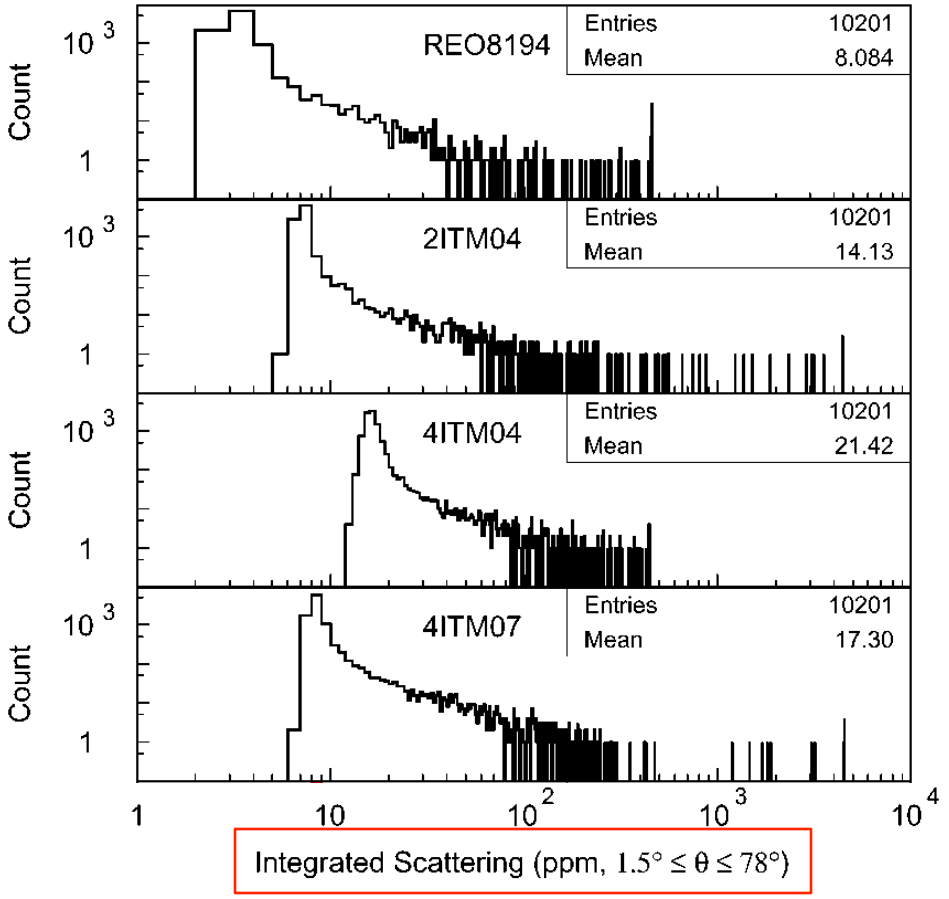
Title: 4ITM01 side 1

**Microroughness was also Measured**

**Before : 0.26 nm rms**
**After : 0.72 nm rms**

# Scatter histograms
# An indication of etching

- Lower end represents the base microroughness
- High end represents point defects
- See LIGO-G080162 for details



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# Advanced LIGO

- Status
- Capability
- Interesting coating behavior
  - » Still in the speculation phase

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# aLIGO Arm Cavity Loss: Early results are in line with budget

| Cavity loss – 2 surfaces (ppm) | Budget 2010 based on specs (ppm) | Actuals 2012 based on (n of 20) (ppm) |
|---|---|---|
| Microroughness scatter | 8 | 2.2 (avg. of 20) |
| Defects (Polish, Coating, Contamination) | 26 | 15 (sample of 2) pol, coat |
| Coating Absorption* | 0.6 | 0.6 (sample of 2) |
| Surface Figure Error & Diffraction | 24 | 3 ppm on coated ITM<br>21 ppm estimated on coated ETM |
| ETM Transmission | 5 | No data yet |
| Total ( required < 75 ppm) | 64 | 42+ ETM trans. |

**50ppm budget remaining for contamination and coating induced surface figure error.**

*** One TM trial surface had unexplained high absorption – no cause has been identified, no repeat of the problem**

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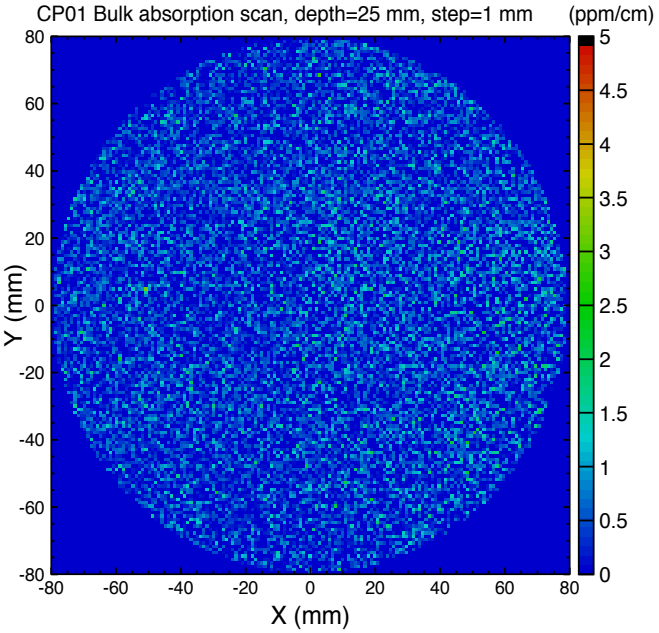
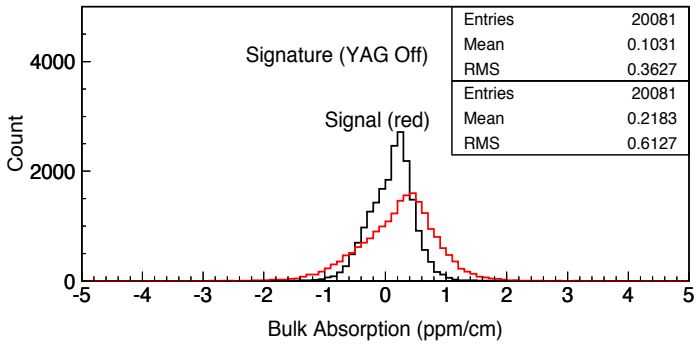
# Quick summary of aLIGO ITM polish

| Serial Number | ROC | Figure (-TPA) |
|---|---|---|
| ITM01 | 1939.32 | 0.10 |
| ITM03 | 1939.52 | 0.08 |
| ITM04 | 1938.61 | 0.15 |
| ITM05 | 1939.18 | 0.10 |
| ITM06 | 1937.60 | 0.09 |
| ITM07 | 1938.53 | 0.10 |
| ITM08 | 1938.44 | 0.16 |
| ITM09 | 1938.15 | 0.11 |
| ITM10 | 1938.15 | 0.14 |
| ITM11 | 1939.39 | 0.18 |

**Follow our progress at https://nebula.ligo.caltech.edu/optics/**

# Heraeus 3000 series Suprasil measurable absorption?




**OH content for 3000 series is 100 times lower than for the 300 series glass**

**Signal (red): 0.21 ppm**
**Background: 0.10 ppm**

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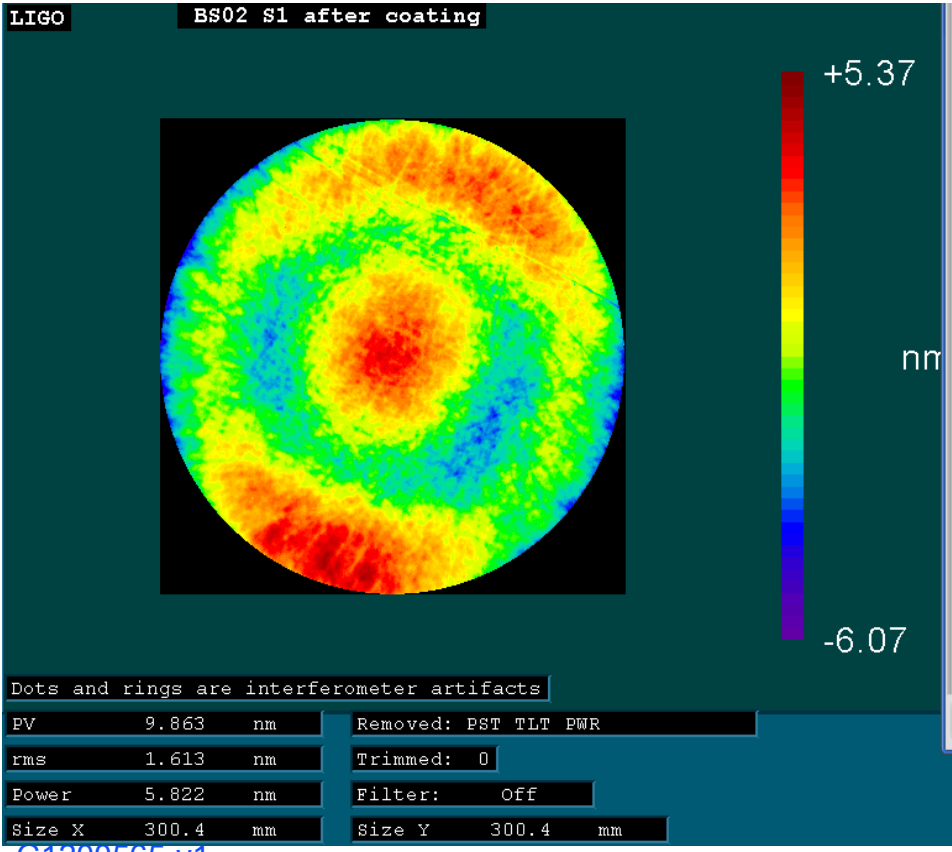
# Metrology

- Zygo full aperture interferometer is installed and operating at Caltech
- All metrology flats and spheres are complete
- The instrument and environment are quite stable, showing a uniform noise floor of 0.1 to 0.15 nm rms.
  - » Polishing requirement is 0.3 nm rms
  - » Vendor reports some surfaces at 0.08 nm rms
- Good agreement with Polishing vendor measurements

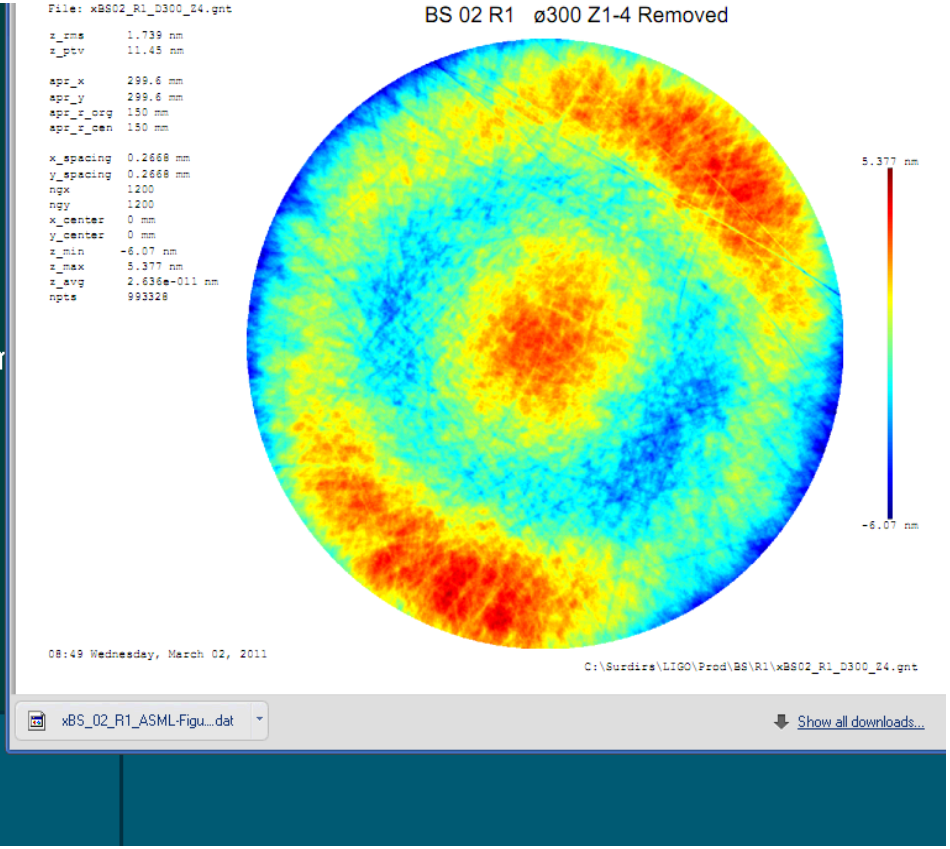
# Figure, before and after coating measured on different instruments

**Same diameter same color scale**

**LIGO measurement after coating by CSIRO**
**9.8 nm PV 1.6 nm rms**




**Polisher (Zygo EPO) measurement**
**11.4 nm PV 1.7 nm rms**



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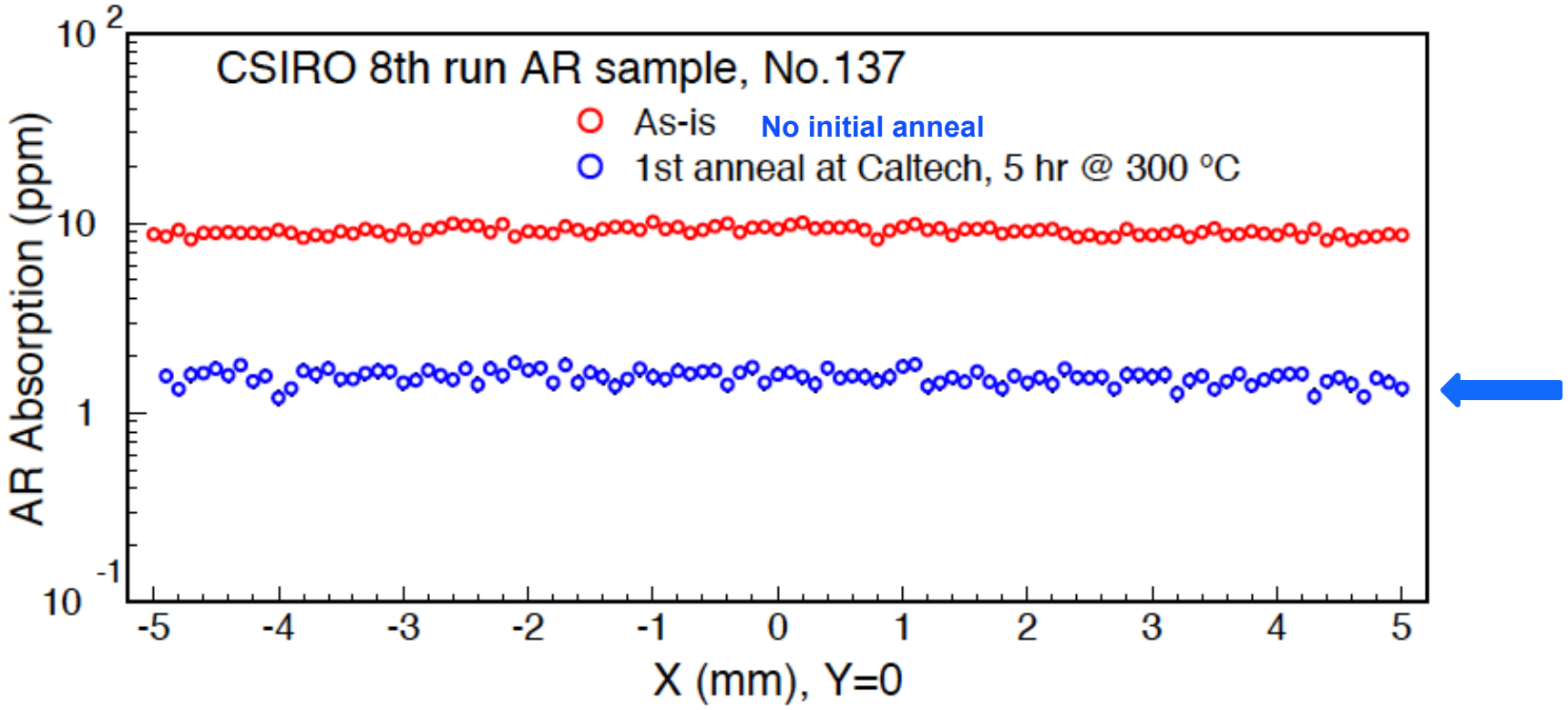
# AR coating absorption surprise

- AR coating absorption is not the same as HR
  - » Most IBS HR absorption is now < 1 ppm, AR up to 10 ppm
- Many samples used to explore the parameters
  - » Film thickness – thinner is more sensitive to annealing temp
  - » Annealing temperature – sensitive to 25 C° variations

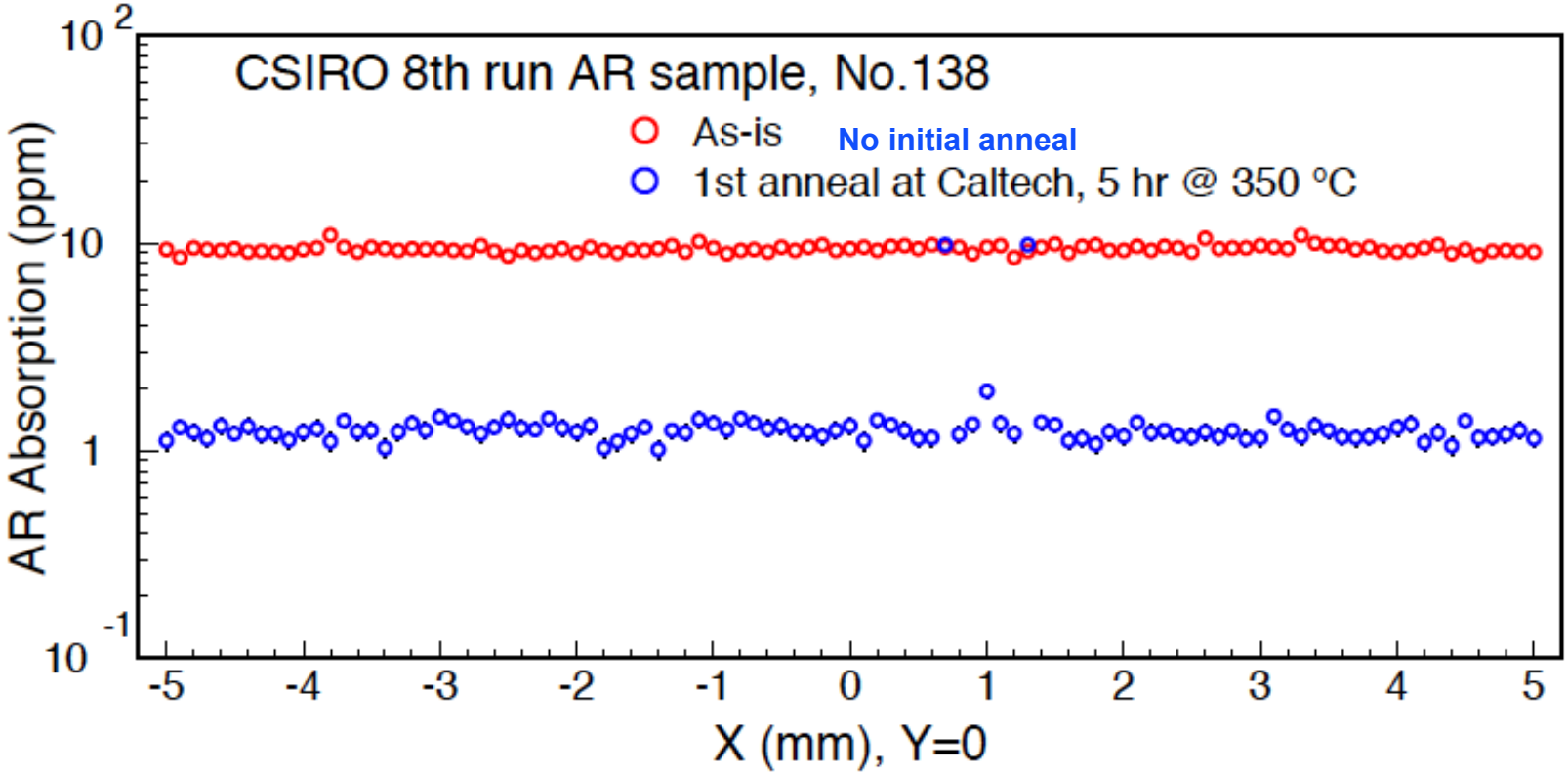
- Unintentional experiment:
  - » ~1nm of Silica added to top Silica layer AFTER the initial 400 C anneal (to tune reflectivity)
  - » Second anneal at 300 C° → Absorption of 4 ppm
  - » Third anneal at 400 C → Absorption < 0.5 ppm

# AR Absorption – 300 C°
# Too much absorption



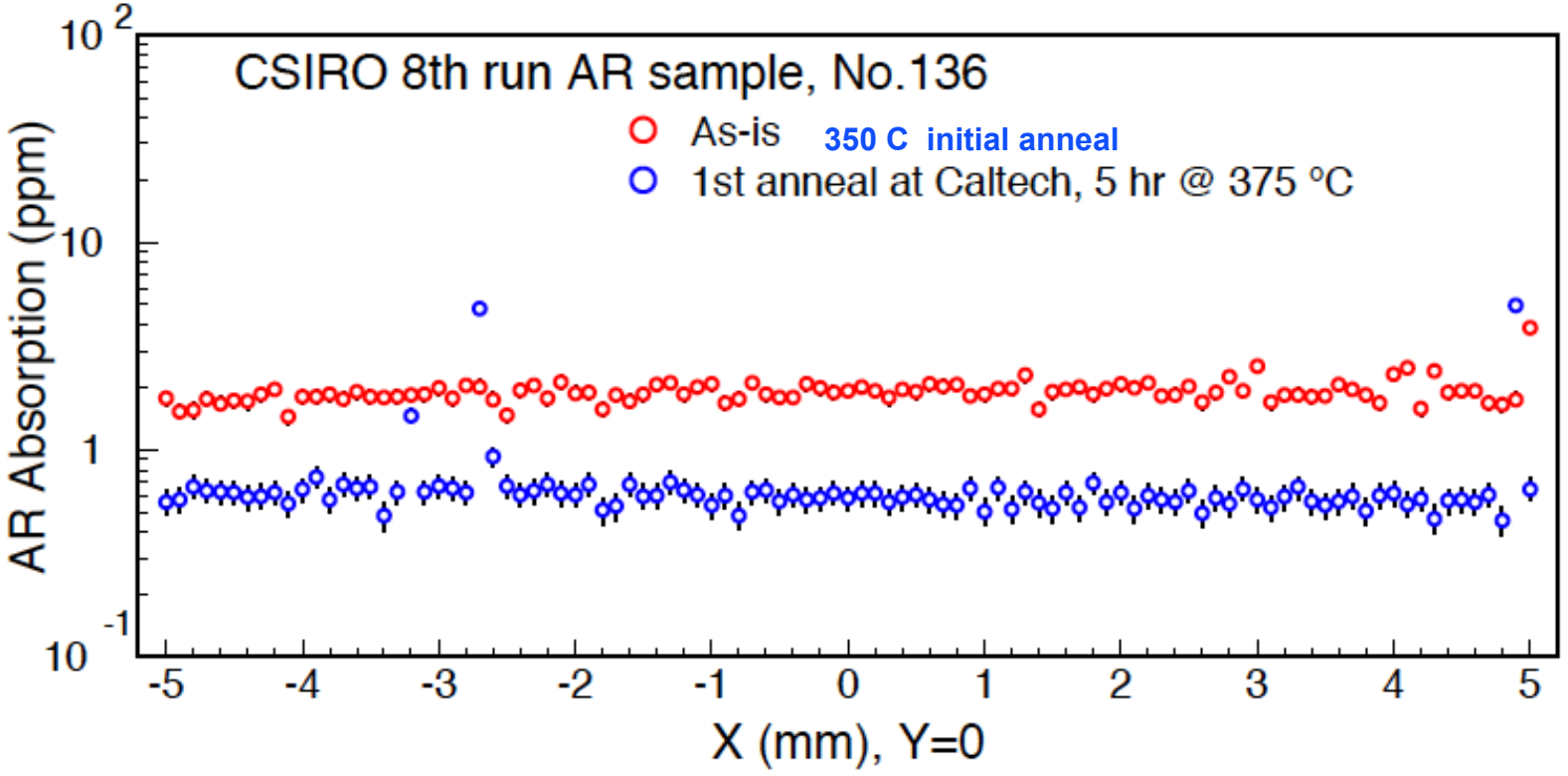

**Absorption of CSIRO AR test sample Measured by Zhang at Caltech**
**Design < 1/20 wave Tantala + ¼ wave Silica**

# AR Absorption – 350 C° still too much absorption



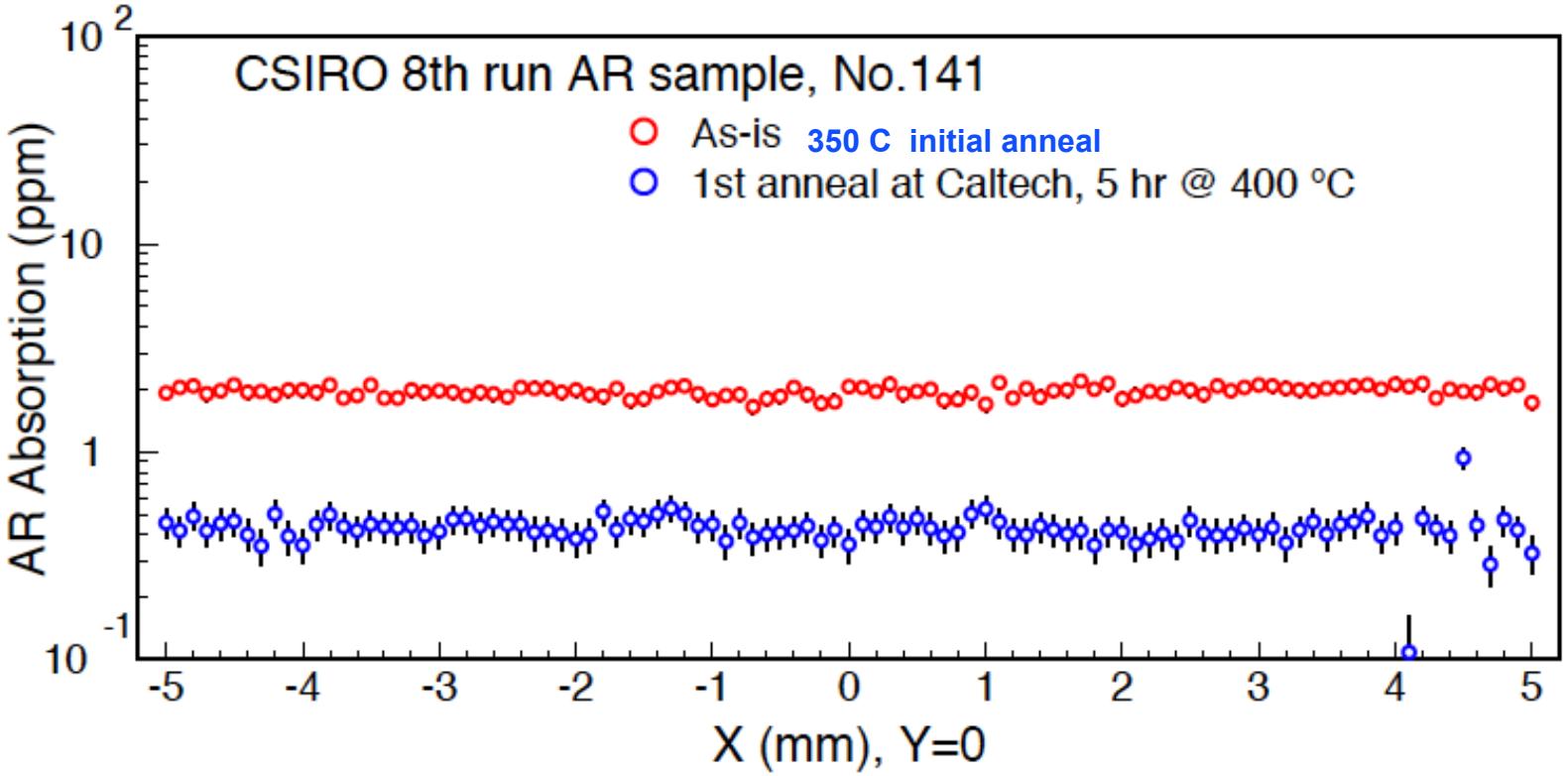

**Absorption of CSIRO AR test sample Measured by Zhang at Caltech**
**Design < 1/20 wave Tantala + ¼ wave Silica**

# AR Absorption – 375 C° better



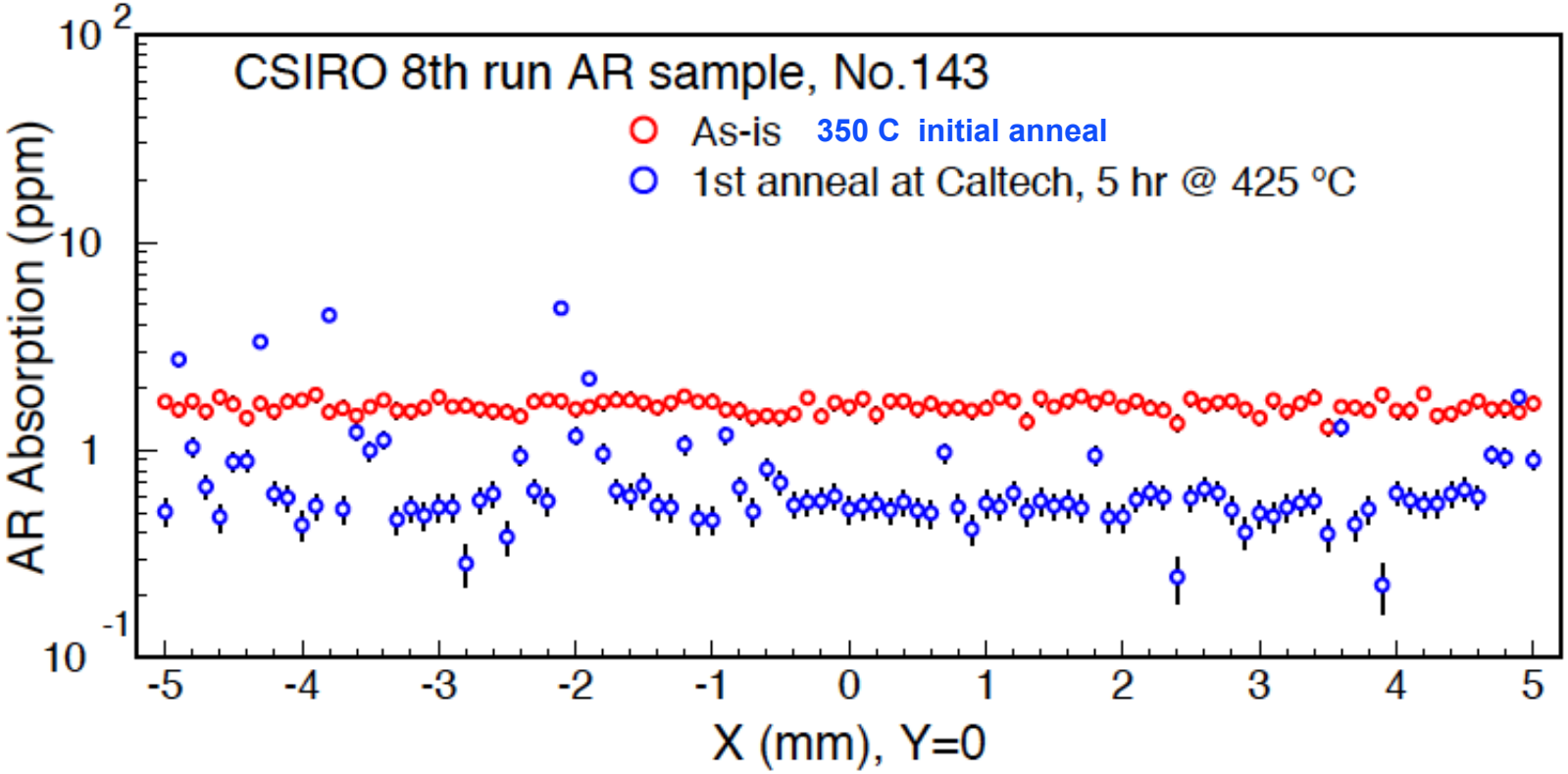

**Absorption of CSIRO AR test sample Measured by Zhang at Caltech**
**Design < 1/20 wave Tantala + ¼ wave Silica**

# AR Absorption – 400 C° even better




**Absorption of CSIRO AR test sample Measured by Zhang at Caltech**
**Design < 1/20 wave Tantala + ¼ wave Silica**

# AR Absorption – 425 C° too far!




**Absorption of CSIRO AR test sample Measured by Zhang at Caltech**
**Design < 1/20 wave Tantala + ¼ wave Silica**

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# Next generation

- Thinking about non-spherical surfaces ….

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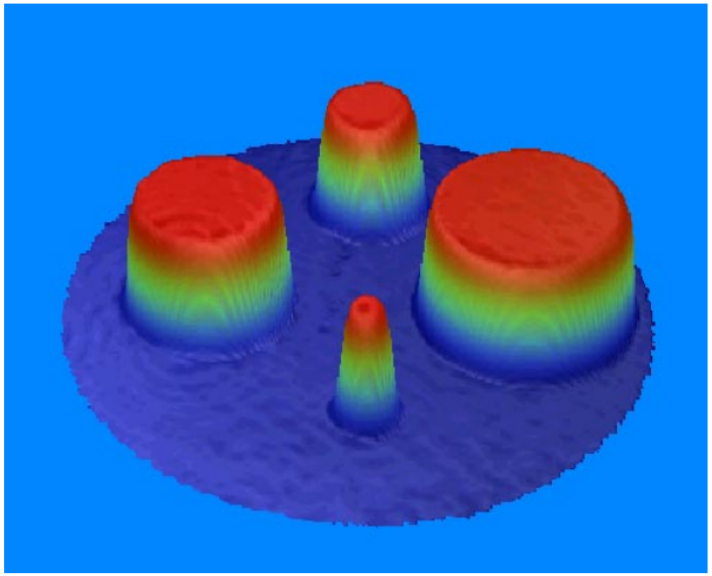
# Future – sculpt your own surface

- Difference from a sphere
  - » < 100 nm in any area where scatter loss is important
  - » Surface slope up to ~ 20nm/mm
  - » Current vendors can't handle much larger optics
- Ion beam figuring can sculpt silicon as well as silica… others.



**This data is inverted for display, ion beams removed material**

**Data and demonstration by CSIRO**

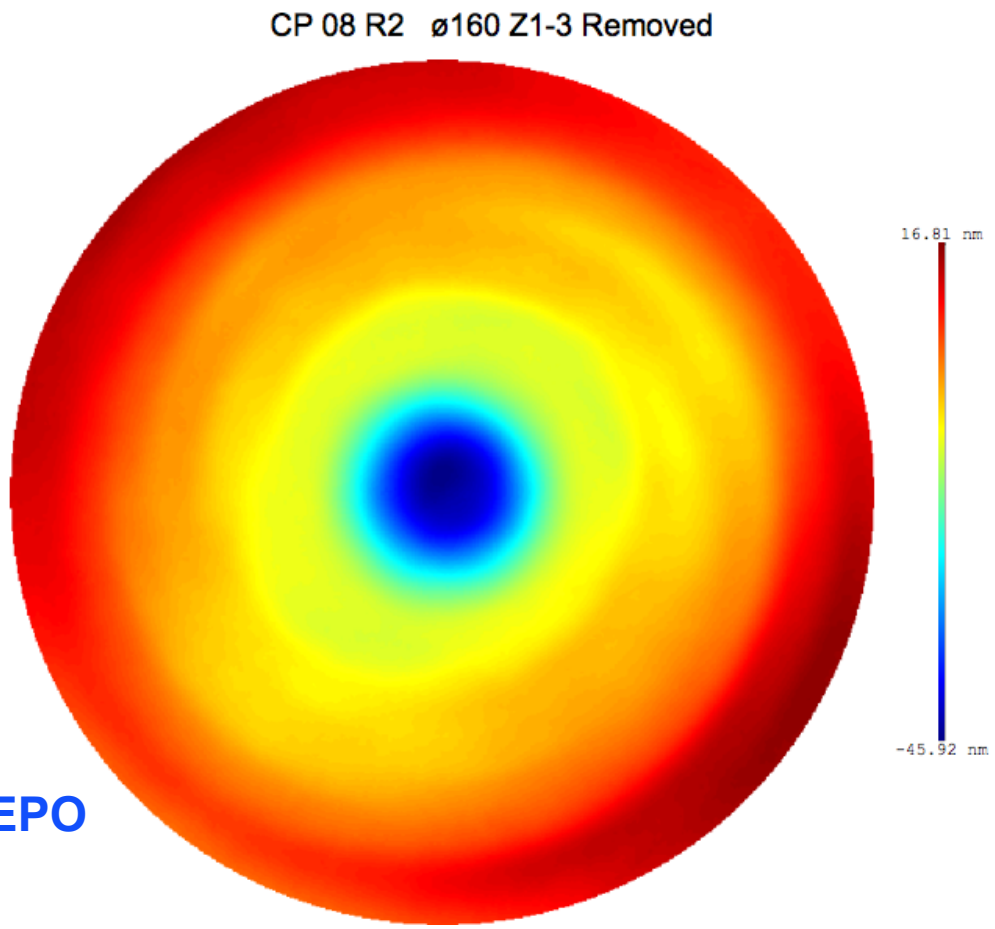
# LIGO Correcting inhomogeneity of Heraeus 3001 by Ion beam figuring of side 2

```
File: xCP08_R2_D160_Z3.gnt

z_rms       10.36 nm
z_ptv       62.72 nm

apr_x       159.9 mm
apr_y       159.9 mm
apr_r_org   80 mm
apr_r_cen   80 mm

x_spacing   0.2669 mm
y_spacing   0.2669 mm
ngx         1200
ngy         1200
x_center    0 mm
y_center    0 mm
z_min      -45.92 nm
z_max       16.81 nm
z_avg      -6.738e-012 nm
npts        282192
```

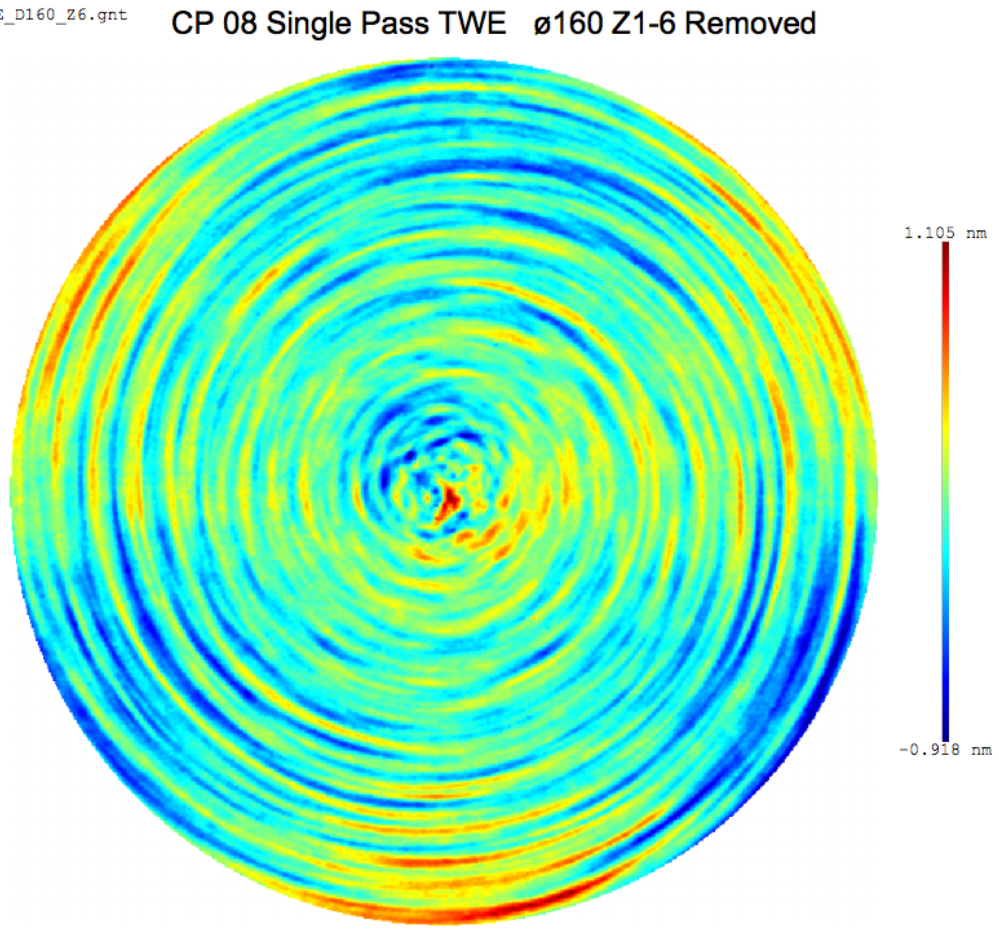



**PV= 63 nm**
**Data and work by Zygo EPO**

# Resulting Transmitted wavefront Corrected s2 plus bulk

File: xCP08_Single_Pass_TWE_D160_Z6.gnt

| | |
|---|---|
| z_rms | 0.2415 nm |
| z_ptv | 2.023 nm |
| apr_x | 159.9 mm |
| apr_y | 159.9 mm |
| apr_r_org | 80 mm |
| apr_r_cen | 80 mm |
| x_spacing | 0.2669 mm |
| y_spacing | 0.2669 mm |
| ngx | 1200 |
| ngy | 1200 |
| x_center | 0 mm |
| y_center | 0 mm |
| z_min | -0.918 nm |
| z_max | 1.105 nm |
| z_avg | -1.035e-011 nm |
| npts | 282192 |




**PV= 2 nm**
**rms = 0.24 nm**
**Data and work by Zygo EPO**

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# Summary

- Part per million losses matter!!!
- We know a lot more about cleaning and metrology
- We are well positioned to handle an optical upgrade as long as the test mass size does not increase dramatically